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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NORDA Report 168	5. MONITORING ORGANIZATION REPORT NUMBER(S) NORDA Report 168
6. NAME OF PERFORMING ORGANIZATION Naval Ocean Research and Development Activity	7a. NAME OF MONITORING ORGANIZATION Naval Ocean Research and Development Activity
6c. ADDRESS *(City, State, and ZIP Code)* Ocean Science Directorate NSTL, Mississippi 39529–5004	7b. ADDRESS *(City, State, and ZIP Code)* Ocean Science Directorate NSTL, Mississippi 39529–5004
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Ocean Research and Development Activity — 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)* Ocean Science Directorate NSTL, Mississippi 39529–5004	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO.: 63704N; PROJECT NO.: ; TASK NO.: ; WORK UNIT NO.:

11. TITLE *(Include Security Classification)*
Ocean Wind and Wave Model Comparison with GEOSAT

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Yr., Mo., Day)*	15. PAGE COUNT
Final	From ______ To ______	December 1986	5

16. SUPPLEMENTARY NOTATION
*Planning Systems, Inc., Slidell, Louisiana 70458

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB. GR.	GEOSAT, satellite data, winds, waves, wave model

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

By comparing operational wind and wave models to GEOSAT, we found that on 10 March 1986, the Federal Republic of Germany had the best skill score for a regional wind analysis, NOAA had the best score for a global wind analysis, the Netherlands had the best score for a regional wave analysis, and the U.S. Navy had the best score for a global wave analysis.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ■ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL R. L. Pickett	22b. TELEPHONE NUMBER *(Include Area Code)* (601) 688-4882 — 22c. OFFICE SYMBOL Code 331

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

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SECURITY CLASSIFICATION OF THIS PAGE

Naval Ocean Research and Development Activity
December 1986 NORDA - ~~Report~~ 168

Ocean Wind and Wave Model Comparisons with GEOSAT Satellite Data

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Dec. 1986

Foreword

The United States Navy is committed to providing the best available environmental products to the Fleet. To this end, NORDA is comparing various operational wind and wave models in use around the world to the Navy's models. This report describes such a comparison for one day using a wind- and wave-measuring satellite as a reference.

A C Esau

A. C. Esau, Captain, USN
Commanding Officer, NORDA

Executive summary

By comparing operational wind and wave models to GEOSAT, we found that on 10 March 1986, the Federal Republic of Germany had the best skill score for a regional wind analysis, NOAA had the best score for a global wind analysis, the Netherlands had the best score for a regional wave analysis, and the U.S. Navy had the best score for a global wave analysis.

Acknowledgments

This work was supported by the Nonacoustic ASW Oceanography Program, Program Element 63704N, Kenneth M. Ferer, Program Manager.

Contents

Ocean Wind and Wave Model Comparisons with GEOSAT

I. Introduction

The U.S. Navy is evaluating operational wind and wave models to determine if present Navy models need improvements. The evaluation program consists of intercomparing models by using observed wind and wave fields recorded by the GEOdesy SATellite (GEOSAT). The technique is similar to that reported by Cavaleri et al. (1982) and Resio and Vincent (1982), except that they used hypothetical wind and wave fields.

For this evaluation, we compared six operational wind and eight operational wave model analyses to GEOSAT observations for one day (10 March 1986). We tested wind model analyses from Canada, the Netherlands, the Federal Republic of Germany, Japan, the U.S. Navy, and the U.S. National Oceanic and Atmospheric Administration (NOAA). We tested wave model analyses from Canada (both military and civilian), the Netherlands, the Federal Republic of Germany, Japan, the U.S. Navy, NOAA, and a private U.S. company (Offshore and Coastal Technology).

II. Method

A. Model data

In order to obtain coincident model output, we requested that all participants send us their analyzed (not forecasted) wind and wave fields for 0000, 0600, 1200, 1800, and 2400 GMT on 10 March 1986. We received the results in a variety of forms, such as magnetic tape, gridded charts, and contoured charts. Next, we saved and edited the GEOSAT wind and wave fields. Finally, we matched the model and GEOSAT fields by computer if we received magnetic tapes, or by hand if we received charts.

B. GEOSAT data

GEOSAT was launched in March 1985 and uses a radar altimeter to estimate wind speeds and wave heights. The altimeter is a narrow-beam, downward-looking, short-pulse radar that bounces signals off the ocean's surface. Since the signals are stored aboard the satellite until it passes over the ground station, wind and wave data are unavailable from 3 to 16 hours after they are sampled. Table 1 summarizes the satellite's characteristics (Kilgus et al., 1984).

Table 1. GEOSAT characteristics.

Orbit:	Altitude	800 km
	Inclination	108°
	Period	101 min
	Ground speed	6.6 km/sec
	Repeat cycle	3 Days
Radar:	Frequency	13.5 GHz
	Max. ocean spot size	25 km
	Effective spot size	2–7 km

Since the satellite is in near-polar orbit and the reflection spot is small, wind and wave coverage consists of narrow north and south tracks. These tracks cover the earth at about 3000 km spacing near the equator and converge near the poles (see Fig. 1).

Significant wave heights are estimated along these tracks by measuring the leading-edge slope of the returning pulse. High seas spread the return pulse and, hence, reduce its slope.

Wind speeds are estimated indirectly. A surface reflection coefficient is calculated from the return pulse magnitude. The pulse is absorbed at the ocean surface by capillary waves and foam, and these factors depend on wind speed. Ground processing is then used to relate the reflection coefficient to surface wind speed by an empirical formula.

The satellite was designed to measure significant wave heights within 10% (waves greater than 5 m) or 0.5 m (waves smaller than 5 m), and to estimate wind speeds within 1.8 m/sec (Kilgus et al., 1984). To check this accuracy, we first edited GEOSAT data (to eliminate transmission errors, islands, and ice), and then matched times and locations to the NOAA buoy network. Figures 2 and 3 compare GEOSAT wind speeds and wave heights to those recorded by the NOAA buoys (within 30 min and 50 km) during our test. The mean buoy minus GEOSAT wind difference was −0.8 m/sec, and the standard deviation of the difference was 2.2 m/sec. The mean wave difference was 0.1 m and the standard deviation was 0.4 m.

The scatter in Figures 2 and 3 has several sources. For example, buoys average over time (8 min for wind, 20 min

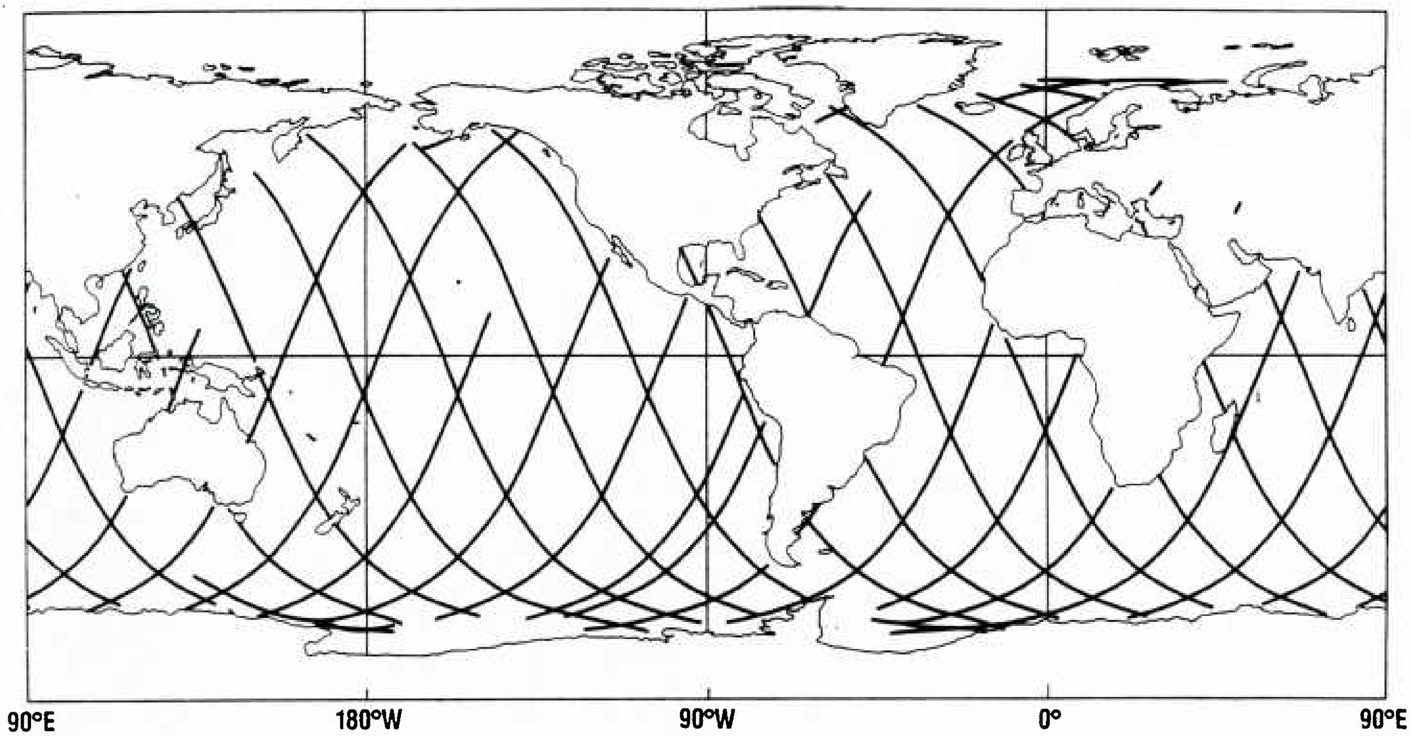

Figure 1. Track of GEOSAT on ocean's surface during test day of 10 March 1986. Gaps result from editing.

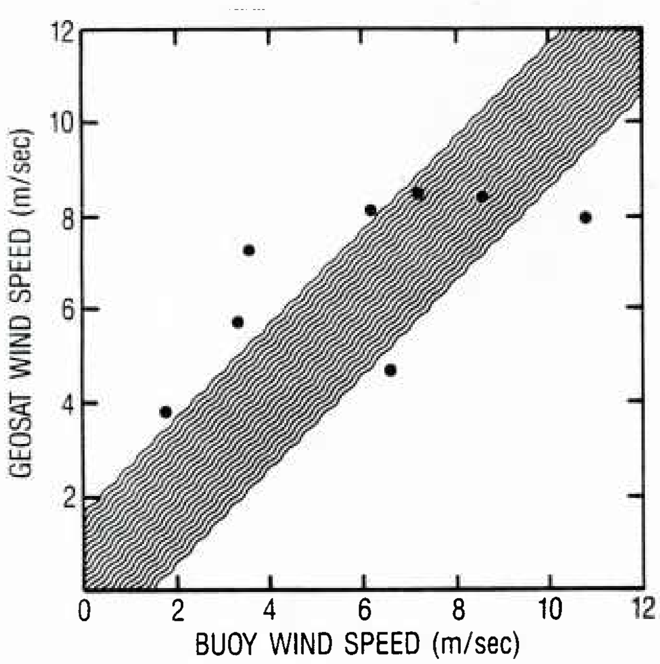

Figure 2. Comparison of wind speeds recorded by NOAA buoys and GEOSAT. Satellite observations were within 30 min and 25 km of matching buoy observation. Shaded band is satellite design accuracy.

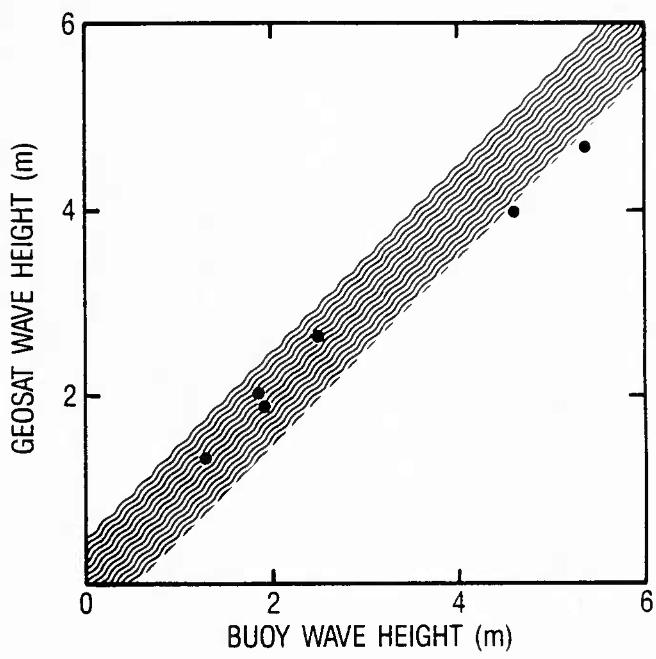

Figure 3. Comparison of significant wave heights recorded by NOAA buoys and GEOSAT. Satellite observations were within 30 min and 25 km of matching buoy observation. Shaded band is satellite design accuracy.

for waves), and the satellite averages over space (maximum of 25 km, but most of the highest energy return comes from an area 2–7 km from the center). Also, the satellite sensor errors (1.8-m/sec wind, 0.5-m wave height), shown as shaded areas on the plots, are independent of the buoy sensor errors (1 m/sec wind, 0.5 m wave height). All these sources of scatter are mixed in Figures 2 and 3. In spite of these error sources, however, these few buoy-satellite comparisons suggest that GEOSAT is useful for model verification.

C. Comparison data

To use the satellite data discussed above, we selected those wind and wave points on the 10 March 1986 GEOSAT tracks that were within 1.5 hours of model analysis times. Next, if we were provided magnetic tapes, we computer scanned all model values for GEOSAT values that were within 50 km. If we were provided contour charts, the process was more subjective. We plotted GEOSAT tracks on the model output and read off overlapping points.

The matched sets of data pairs from the satellite and models were then arranged in tables by separating them into three classes: light, moderate, and heavy. Class boundaries were selected so that nearly equal numbers of satellite observations occurred in each class. This selection was done to eliminate any advantage of a model forecasting the most probable class.

Comparing a class row and column sum in these tables shows whether that class occurred as often in the model as it was observed. A column sum that is larger than the row sum for the same class indicates that the model overpredicted that class. The opposite is also true: a smaller column sum, relative to a row sum, means that the model underpredicted that class (Panofsky and Brier, 1965).

An overall skill score was also calculated from the matched data pairs. To calculate this score, values were combined into a single number, defined by

$$SS = (R-E)/(T-E) \ ,$$

where

SS = skill score,
R = number of times model results agreed with GEOSAT (sum of observations on major diagonal),
E = number of times model results agreed with GEOSAT due to chance (formula given below),
T = total number of model minus GEOSAT pairs.

E was calculated by multiplying each column sum by the row sum for that class, adding these column-row products, and dividing by T.

The above skill score ranges from 1, when all model minus GEOSAT pairs agree (all pairs fall on the diagonal), to 0, when the number of pairs agreeing is expected by chance.

Table 2. Distribution of pairs of U.S. Navy model (wind model at top, wave model at bottom) and GEOSAT satellite data for 10 March 1986. Data pairs are within 1.5 hours and 50 m of each other. Table values have been converted to percentages.

Navy global wind model (%)

GEOSAT %	Light	Medium	Heavy	Sum
Light	36	7	4	47
Medium	14	7	14	35
Heavy	3	0	15	18
Sum	53	14	33	100

Number of observations = 138

Skill score = 0.35

Light = 0 to 6 m/s   Medium = >6 to 10 m/s   Heavy = >10 m/s

Navy global wave model (%)

GEOSAT %	Light	Medium	Heavy	Sum
Light	27	11	1	39
Medium	12	17	7	36
Heavy	2	2	21	25
Sum	41	30	29	100

Number of observations = 243

Skill score = 0.48

Light = 0 to 2 m   Medium = >2 to 3 m   Heavy = >3 m

III. Results

A summary of the wind model results is shown in Table 3 (units are meters per second), and a summary of the wave model results are shown in Table 4 (units are meters). The left side of each table shows regional models, and the right side shows global models. In the bottom row, as a reference for the model minus GEOSAT statistics, are the buoy minus GEOSAT means and standard deviations.

Each model entry covers one row in the table. The row contains the mean difference of the matching data pairs (model minus GEOSAT), the standard deviation of these differences, the number of data pairs, and the skill score calculated by the formula given in Table 4.

To estimate variability in Tables 3 and 4, we ran Navy wind and wave model comparisons with GEOSAT on two other days. We found day-to-day variability on the order of ±0.1 for means, ±0.3 for standard deviations, and ±0.1 for skill scores.

The Federal Republic of Germany had the best skill score for a regional (North Atlantic) wind chart, NOAA had the best score for a global wind chart, the Netherlands had the best score for a regional (North Atlantic) wave chart, the U.S. Navy had the best score for a global wave chart.

Table 3. Differences between wind models and GEOSAT data on 10 March 1986. The statistics of the differences and the skill score (defined in text) are given for both regional and global models. Differences between NOAA buoys and GEOSAT are listed in the bottom row.

	Regional				Global			
	Mean (m/s)	St. Dev. (m/s)	Number of Observations	Skill Score	Mean (m/s)	St. Dev. (m/s)	Number of Observations	Skill Score
Canadian Civilian II	0.2	3.1	48	0.33				
Canadian Civilian I	1.1	3.4	47	0.33				
Canadian Military								
Netherlands	2.2	2.8	87	0.22				
Fed. Rep. Germany	1.1	3.7	62	0.37				
Japanese	1.0	2.4	14	*				
U.S. Navy	1.7	3.6	66	0.32	1.1	3.9	138	0.35
U.S. NOAA	0.1	3.1	71	0.32	−1.1	2.8	74	0.50
OCTI								
Buoys					−0.8	2.2	8	*

* Insufficient data to calculate skill score

Table 4. Differences between wave models and GEOSAT data on 10 March 1986. The statistics of the differences and the skill score (defined in text) are given for both regional and global models. Differences between NOAA buoys and GEOSAT are listed in the bottom row.

	Regional				Global			
	Mean (m/s)	St. Dev. (m/s)	Number of Observations	Skill Score	Mean (m/s)	St. Dev. (m/s)	Number of Observations	Skill Score
Canadian Civilian II	0.1	1.3	48	0.53				
Canadian Civilian I	1.8	1.6	38	0.00				
Canadian Military	−0.2	1.5	67	0.31				
Netherlands	0.0	1.1	87	0.58				
Fed. Rep. Germany	0.5	1.0	62	0.29				
Japanese	0.3	0.4	14	*				
U.S. Navy	0.4	0.7	81	0.56	0.2	0.8	243	0.48
U.S. NOAA	−0.7	1.2	129	0.16	−0.1	0.9	393	0.33
OCTI	−0.1	1.3	58	0.42				
Buoys					0.1	0.4	6	*

* Insufficient data to calculate skill score

IV. Conclusions

Our first conclusion is that satellites are the ideal way to validate wind and wave models. When GEOSAT data are properly edited, the satellite provides reasonably accurate global data. In addition, new satellites will soon be launched that will scan side to side, so that the whole ocean surface is covered instead of scanning a narrow path as GEOSAT does. As a result of such data, all wind and wave models should improve.

Our second conclusion is that, considering how little data are routinely available to these operational models, they did fairly well. Most model differences from GEOSAT were not that much larger than the buoy differences from GEOSAT.

Third, we think that model minus satellite comparisons such as those presented here should be automated and run routinely. This procedure would provide an operational method for continually testing relative model performance, or for evaluating new models or data assimilation techniques.

Fourth, from our ratings no clear relationship between advanced model physics and operational performance can be established. The Navy wave model, for example, does not use the latest physics, yet it had a high skill score. These models are probably data limited rather than physics limited.

Finally, we plan to repeat this test on another day. A repeat test will enable us to see if the results in Tables 3 and 4 are consistent or if some models perform better in certain seasons. Since GEOSAT will be turned off and moved to another orbit during October and November 1986, we hope to do a repeat test soon.

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